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CHARACTERIZATION OF OYSTER MUSHROOM-SOY PROTEIN MEAT ANALOG USING SINGLE-SCREW EXTRUDER WITH EXTRUSION VARIABLES

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fullfilment of the Requirements for the Degree of Master of Science

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Chair : Rosnita A. Talib, PhD
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The most difficult aspects of the meat analog extrusion are attaining desirable product's appearance and texture. Using a single-screw extruder and incorporating low-grade oyster mushroom into soy proteins can produce a fibrous-structured meat analog. Thus, three research objectives of this study were to determine suitable extrusion process parameters range (barrel temperature and screw speed). Next, evaluate the effects of different screw speeds and oyster mushroom (OM) addition on the meat analog's physical, microstructure, and textural characteristics. Then, model the effect of screw speed and OM addition on the extrusion specific mechanical energy (SME). Satisfactory extrudates were obtained at a barrel temperature of 140 °C, screw speed range of 100 rpm - 160 rpm, and OM addition at 0%, 7.5%, and 15% via factorial experiments. Single-screw extrusion equipped with a slit die successfully produced expanded oyster mushroom-soy protein extrudates. However, the increase in the OM content significantly decreased ($p \leq 0.05$) the expansion ratio of the extrudate from 1.26 to 0.98. This result indicated that adding more OM restrained the expansion ratio. The extrudates had a medium density range (maximum of 1393.70 ± 6.30 kg/m^3). By adding OM, the extrudates attained a higher moisture content (range = 34.77% to 37.93%) than the extrudates containing the protein mixture only (range = 26.99% to 32.33%). The increase in screw speed and OM significantly increased ($p \leq 0.05$) the water absorption index. The increase in the texturization index was significantly influenced ($p \leq 0.05$) by OM addition rather than the screw speed. A defined fibrous structure supported the high texturization index and small shape of air cells observed in the extrudates. The effect of screw speed and OM addition on the texture characteristics (hardness, gumminess, and chewiness) and SME was determined via factorial experiment design. Compared with the effect of OM addition, the impact of individually increased screw speeds was minimal. However, the combined effects of screw speed and OM addition had significantly reduced ($p \leq 0.05$) all the texture characteristics. The hardness (3521.35 g) and

gumminess (2717.85) of the meat analog extruded at the maximum screw speed (160 rpm) and 15% OM addition are close to the chicken breast characteristics, respectively. The oyster mushroom–soy protein extrudates are chewier compared to the non-extruded texturized vegetable protein (TVP) and chicken meats. The SME values of the single-screw extrusion were linearly affected by the increasing screw speeds, which also lies in the adequate range (< 200 kJ/kg) for meat analog production. Applying the superposition technique successfully shifted the individual linear curves of the SME into a smooth master curve. The relationship of screw speeds and SME can be observed to describe the extruder's performance in the production of oyster mushroom-soy protein meat analogs. These findings suggest that oyster mushroom-soy protein meat analogs with satisfying appearance, physical and texture characteristics are best produced via single-screw extrusion at a barrel temperature of 140 °C, screw speed of 160 rpm, and 15% OM addition.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENCIRIAN DAGING ANALOG CENDAWAN TIRAM-PROTEIN SOYA MENGGUNAKAN MESIN PENYEMPERITAN JENIS SKRU-TUNGGAL DENGAN PEMBOLEH UBAH PENYEMPERITAN

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Aspek yang paling sukar bagi penyemperitan daging analog adalah memperolehi penampilan dan tekstur produk diingini. Menggunakan sebuah mesin penyemperitan skru-tunggal dan menambahkan cendawan tiram bermutu-rendah ke dalam protein soya dapat menghasilkan daging analog berstruktur-serat. Oleh itu, tiga objektif bagi kajian ini adalah untuk menentukan julat sesuai parameter proses penyemperitan (suhu tong dan kelajuan skru). Seterusnya, menilai kesan kelajuan skru yang berbeza dan penambahan cendawan tiram pada fizikal, struktur mikro, dan ciri tekstur daging analog. Kemudian, modelkan kesan kelajuan skru dan penambahan cendawan tiram pada tenaga mekanikal khusus penyemperitan. Ekstrudat yang memuaskan telah diperoleh pada suhu tong 140 °C, julat kelajuan skru 100 rpm - 160 rpm, dan penambahan cendawan tiram pada 0%, 7.5%, dan 15% melalui eksperimen faktorial. Mesin penyemperitan skru-tunggal yang dipasang dengan acuan celah berjaya menghasilkan daging analog cendawan tiram-protein soya terkembang. Walau bagaimanapun, peningkatan dalam kandungan cendawan tiram telah berkurang secara ketara ($p \leq 0.05$) nisbah pengembangan ekstrudat dari 1.26 ke 0.98. Keputusan ini menunjukkan bahawa penambahan lebih banyak cendawan tiram mengekang nisbah pengembangan. Ekstrudat mempunyai julat ketumpatan sederhana (maksimum 1393.70 ± 6.30 kg/m^3). Dengan menambahkan cendawan tiram, ekstrudat memperoleh kandungan kelembapan lebih tinggi (julat = 34.77% hingga 37.93%) berbanding ekstrudat yang mengandungi campuran protein sahaja (julat = 26.99% hingga 32.33%). Peningkatan kelajuan skru dan penambahan cendawan tiram meningkat secara ketara ($p \leq 0.05$) indeks penyerapan air. Peningkatan dalam indeks penteksturan dipengaruhi secara signifikan ($p \leq 0.05$) oleh penambahan cendawan tiram berbanding kelajuan skru. Struktur berserat yang teratur menyokong indeks penteksturan tinggi dan bentuk sel udara kecil yang diperhatikan dalam ekstrudat. Kesan kelajuan skru dan penambahan cendawan tiram pada ciri tekstur (kekerasan, kebergetahan, dan kekenyalan) dan tenaga mekanikal

khusus ditentukan melalui reka bentuk eksperimen faktorial. Berbanding dengan kesan penambahan cendawan tiram, kesan peningkatan kelajuan skru secara individu adalah minimum. Walau bagaimanapun, kesan gabungan kelajuan skru dan penambahan cendawan tiram telah mengurangkan secara signifikan ($p \leq 0.05$) semua ciri tekstur. Kekerasan (3521.35 g) dan kebergetahan (2717.85) daging analog yang tersemperit pada kelajuan skru maksimum (160 rpm) dan 15% penambahan cendawan tiram adalah hampir dengan ciri dada ayam, masing-masing. Ekstrudat cendawan tiram-protein soya lebih kenyal berbanding dengan protein sayuran bertekstur tak-disemperit dan daging ayam. Nilai tenaga mekanikal khusus bagi penyemperitan skru-tunggal dipengaruhi secara linear oleh peningkatan kelajuan skru, yang juga terletak pada julat yang mencukupi (< 200 kJ/kg) untuk pengeluaran daging analog. Penggunaan teknik superposisi berjaya mengalihkan lengkung lelurus individu bagi tenaga mekanikal khusus ke lengkung induk yang lancar. Hubungan kelajuan skru dan tenaga mekanikal khusus dapat dilihat untuk menggambarkan prestasi mesin penyemperitan dalam pengeluaran daging analog cendawan tiram-protein soya. Penemuan ini mencadangkan bahawa daging analog cendawan tiram-protein soya dengan ciri penampilan, fizikal, dan tekstur yang memuaskan paling baik dihasilkan melalui penyemperitan skru-tunggal pada suhu tong 140 °C, kelajuan skru 160 rpm, dan 15% penambahan cendawan tiram.

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LIST OF ABBREVIATIONS

3D	Three-dimensional
CAGR	Compound annual growth rate
CEO	Chief executive officer
CPO	Crude palm oil
ER	Expansion ratio
FAMA	Federal Agricultural Marketing Authority, Malaysia
FAO	Food and Agriculture Organization
FDA	Food and Drug Administration
HLB	Hydrophilic-lipophilic balance
HT/ST	High-temperature short-time
ICGN	Iota carrageenan
IPO	Initial public offering
ISP	Isolated soy protein
MPOB	Malaysia Palm Oil Board
MPOC	Malaysia Palm Oil Council
O/W	Oil in water
OM	Oyster mushroom
RTE	Ready to eat
SEM	Scanning electron microscopy
SME	Specific mechanical energy
SP	Soy protein concentrate
SS	Screw speed
TI	Texturization Index

TPA	Texture profile analysis
TPM	Ternary protein mixture
TVP	Texturized vegetable protein
W/O	Water in oil
WAI	Water absorption index
WG	Wheat gluten
E322	Lecithin
NaCl	Sodium chloride
$Na_2S_2O_5$	Sodium metabisulfite
rpm	Rotation per minute
W	Weight of extrudate
D^2	Dimension of (width × height)
L	Length of the extrudate
ρ_{app}	Apparent density of the extrudate
π	Pi
min	Minute
F_V	Crosswise strength
F_L	Lengthwise strength
n	Screw speed
T	Motor torque at steady-state condition
$\dot{m}$	Mass flow rate
R^2	Regression coefficient
RMSE	Root mean square error
SSE	Sum of square error

SST	Total sum of squares
$Y_{experimental}$	Experimental value of the dependent variable
Y_{model}	Model value of the dependent variable
$\bar{Y}_{experimental}$	Mean of the experimental value of the dependent variable
N	The number of data
α	Dimensionless shift factor
ANOVA	Analysis of variance
r	Pearson coefficients
p-value	Probability value

CHAPTER 1

INTRODUCTION

1.1 Research Background

The combined effects of increasing human population worldwide, awareness on animal-based protein sustainability, environmental concerns, and human health considerations (such as diseases from the animal, uncontrolled sanitary farming environment, and others), causing the production of meat analogs expected to increase the global market venue of plant protein-based meat to USD 7.5bn by 2025 (Askew, 2019). The world farming and meat industry has been facing enormous challenges such as arable land shrinkage, intensification of agricultural production, and livestock challenge to meet the world meat demand (Gerhardt et al., 2019). In comparison, the world's population eating preferences over animal proteins become more interested in replacing the animal protein source with plant protein for many customers. These factors lead to the importance of plant-based meat in the current trend of a healthy diet and as a future sustainable food.

The Food and Agricultural Organization (FAO) has reported that the intake of meat analog by the consumers in developing countries continues to increase and forecast to increase up to 73% by 2050 (FAO, 2020). Plant-based meat is highly marketed in Western countries, and Asian countries will also become a future market due to growing interest in meat imitations (Ismail et al., 2020). From a survey done in 2018, approximately 40% of the respondents in Malaysia would like to substitute animal meat with plant protein-based meat in their meals (Hirschmann, 2019). This change in trend is due to the health benefits of plant protein-based meat analogs, which are low in saturated fats and sodium, cholesterol-free, and an excellent source of protein that is comparable to animal meat (Asgar, 2010; Maida, 2017). Furthermore, meat analogs can possibly be labeled as halal food whereby there is no slaughtering process issue of animal meat involved and only plant-based ingredients are used.

The addition of the extra element of health-promoting ingredients is an approach to make the meat analog more nutritious and to improve its texture. Several researchers have considered the effects of adding extra ingredients (e.g., flavor enhancer, starch, fiber, microalgae) on the final quality (e.g., expansion, density, color, texture, water absorption capacity) of meat analogs (Milani et al., 2014; Thadavathi et al., 2019; Ma and Ryu, 2019; Caporgno et al., 2020). These studies have reported that the presence of additional ingredients in the protein-based mixtures can positively and negatively affect the physical quality and improve the nutrient content of meat analogs.

Oyster mushrooms (OM) (*Pleurotus sajor-caju*) are widely planted and consumed in Malaysia because of its simple planting cycle and great taste (Mat Amin et al., 2013). Oyster mushrooms are low in fat and calories but are rich in protein, dietary fiber, vitamins, and minerals (Wan Rosli et al., 2015). Mushrooms have been used as meat replacers in human diets due to their good source of macronutrients (protein, fiber), and micronutrients (essential amino acids, vitamins, essential minerals), as well as low fat, sodium, and energy contents (Croan, 2004; Synytsya et al., 2008; Asgar et al., 2010; Ahmed et al., 2016). Mushrooms have been substituted in the development of beef/chicken patties and nuggets to develop healthier protein foods with a good appearance, taste, and texture (Wan Rosli et al., 2011; Miller et al., 2014, Banerjee et al., 2020). A previous study conducted by Ahirwar et al. (2015) reported the effect of fresh button mushroom addition in a wheat gluten-based meat analog through the steaming method. However, their study was only limited to the hardness and nutritional properties of the meat analog.

Traditionally, meat analog has been produced through a simple processing or fermentation process that failed to exhibit the mimic texture of animal meat. However, with the modern advance technology in processing and food science, meat analog products, which have mimic aesthetic qualities (e.g., texture, taste, and look) and functionality of animal meat product can be produced (King and Lawrence, 2019). Recent studies have developed a nutritious plant protein-based meat analog that mimics the aesthetic quality of animal meat. These studies have attempted to develop plant protein-based meat analogs from different sources of protein (e.g., soybean, peanut, oilseed, cereal, mycoprotein) (Rehrah et al., 2009; Asgar et al., 2010). Different cooking techniques (e.g., single-screw extrusion, twin-screw extrusion, Couette cell technology, electrospinning) were applied (Thadavathi et al., 2019; Caporgno et al., 2020; Krintiras et al., 2016; Nieuwland et al., 2014). Among the technologies applied, extrusion is the most popular single-step process for forming meat analogs with satisfying appearance and texture.

The extrusion cooking technique is commercially applied in the production of meat analog. Extrusion is a continuous process of mixing, kneading, and shaping that involves both thermal and mechanical energies. It is a versatile cooking technique that can be applied to produce varieties of food such as cereals, meat analogs, and ready-to-eat food. Extrusion is a high-temperature short-time (HTST) process that is remarkably adaptable in fulfilling consumer demand for attractive products. The production of various food products is workable by simultaneously adjusting the conditions of feed ingredients and the setting parameters of the extruder. Feed ingredients generally consist of multiple components that will experience different structural transformations under extrusion cooking in the presence of heat, shear force, and water. In the extrusion of proteins, their original states are disrupted (denaturation of protein) and altered (realign and crosslinking) under high temperature, shear, and pressure. However, protein texturization is also dependent on the type of ingredient used, as the ingredients can enhance or inhibit the desired final product quality. Determining the correct extruder parameters and ingredient formulation to enhance the appearance, taste, and texture of meat analog is the most challenging feature when it comes to extrusion cooking. The right extrusion temperature is important to ensure the completion of the denaturation of proteins during extrusion. Besides, screw speed is crucial to provide the shearing effect in the process of realignment and formation of the fibrous structure of meat analog.

Many studies applied a single-screw extruder for plant protein-based meat analog production (Thadavathi et al., 2019; Omohimi et al., 2014; Rehrah et al., 2009; Parmer Jr. and Wang, 2004). According to these studies, using a single-screw extruder for manufacturing meat analog is a viable choice. It is feasible to make meat analogs using single-screw extruders by adjusting the extrusion processing parameters (e.g., temperature, screw speed, and screw configuration) and component composition (e.g., protein sources, moisture level, and binders). However, no study has been conducted to find the relationship of varied screw speeds and the addition of OM on the texture of soy protein-based meat analog and extruder's specific mechanical energy (SME). Thus, the combined effects of extrusion screw speed and low-grade OM addition on the texture characteristics (hardness, gumminess, and chewiness) of oyster mushroom-soy protein meat analog were analyzed. The obtained texture characteristics were compared with commercial products such as hydrated non-extruded texturized vegetable protein (TVP) and chicken meats. It is relevant to consider non-extruded TVP and chicken meats due to their comparable texture (e.g., chewiness, juiciness, gumminess, long fibers, and layered structure) and appearance (e.g., shape, size, and color). That may resemble the characteristics of meat analog developed in this study.

Master curves of drying kinetics, viscosity, and rheological behavior of foods have been established from applying of the superposition technique (Abdullah, 2015). However, the superposition technique's uses in describing the relationship between the physical properties of the extrudate, texture characteristics, sensory qualities, processing performance, and parameters of extrusion are still restricted. The SME is the key factor that reflects the degree of extrusion cooking and is necessary to optimize and scale-up of extrusion processes (Bouvier and Campanella, 2014). As a consequence, process SMEs is essential to be addressed when making master correlations for process-product optimization. In this study, the relationship between SME and screw speed was determined from a master curve developed using the superposition technique. A master curve is developed to display a single smooth line to express the extruder's performance at a wide range of screw speed applied for the extrusion of this type of meat analog.

1.2 Problem Statement

Substantial challenges remain in operation to achieve the right appearance and texture of meat analog. Among the main challenges are determining suitable processing parameters (e.g., temperature and screw speed) and feed compositions in the production of meat analog. Appearance (e.g., expansion ratio, density, water absorption index, and moisture content) and texture (e.g., fibrous structure, hardness, gumminess, and chewiness) of meat analogs are part of the properties where consumers put in priority other than taste when eating them. To meet these demands, it is critical to producing a high protein value meat analog employing high protein plant ingredients such as soy protein, one of the most common ingredients used in meat creation. However, using soy proteins as the only component did not result in a more appealing meat substitute. Therefore, it is convenient to add extra ingredients (e.g., wheat gluten or carbohydrate fibers), which could improve the physical characteristics and texture of meat analogs (Kyriakopoulou et al., 2021). It is hypothesized that the inclusion of OM in soy proteins may enhance the fibrous structure formation, hardness, gumminess, chewiness, and physical properties of meat analogs.

Low-grade OM is classified as no market value category by the Federal Agricultural Marketing Authority (FAMA), Malaysia (2017). They are small size and deformed in shape. Thus, they are usually sold at a much lower price than higher grades or being discarded as mushroom waste. Despite their physical flaws, low-grade OM contains many nutritional contents. Adding these low-grade mushrooms into meat analogs, which mainly contained protein mixture can be a benefit for value adding in the final product. Thus, development of this animal meat-free products will be a great effort in terms of promoting healthier eating meals.

Apart from being specific on the raw materials, operating process parameters (barrel temperatures and screw speed) of extrusion also need to be controlled to sustain both the product quality and the low operating cost of meat analog processing. Selecting and preconditioning of feed mixtures is an important criterion that needs attention to perform a good extrusion ability during extrusion.

1.3 Research Aims and Objectives

This research aims to investigate the extrusion ability of a single-screw extruder for the processing of oyster mushroom-soy protein extrudate. In this research, the oyster mushroom-soy protein meat analog was aimed unpuffed, containing medium moisture (30%< moisture content <50%) and presenting a fibrous structure.

The set objectives are:

I. to determine a range of suitable extrusion process parameters (barrel temperature and screw speed) that satisfy the extrusion performance and extrudate specific criteria,

II. to evaluate the effects of different screw speeds and OM addition on the physical properties (expansion ratio, apparent density, moisture content, water absorption index, and texturization index), microstructure, and textural characteristics of the oyster mushroom-soy protein extrudate, and

III. to model the effect of screw speed and OM addition on the extrusion SME using master curve technique.

1.4 Scope and Significance of Research

There is a growing demand for the replacement of animal-based protein with plant-based protein in food products but with similar aesthetic qualities of foods as expected by consumers. A combination of plant-based ingredients has developed functional food that is important for vegetarians by which they do not consume animal-based food products. It is of interest in the present research to assess the combined effect of low-grade OM addition, and the extrusion process parameters (e.g., barrel temperature, screw speed) on the properties of soy protein-based meat analog as well as the extrusion process behavior (extrusion ability) via single-screw extrusion. To achieve both consumers and food industries' expected quality, it is important to determine different factors that influence the properties of meat analog. This study presented a suitable range of ingredient formulations and processing parameters that satisfy the extrusion ability and extrudate physical characteristic. Determination of the process parameters is likely to benefit the researchers and food industries in the processing of meat analog made of soy proteins via single-screw extrusion.

This study also contributes to the understanding of the physical properties and microstructure changes of meat analogs produced at different extrusion process parameters. The outcomes would be beneficial to understand the extent of extrusion process parameters that affected the meat analog properties and process behavior. The significant positive and negative effects of the extrusion process parameters on the properties of the meat analogs were analyzed using a statistical approach. Also, the oyster mushroom-soy protein meat analog that exhibits a texture that is comparable with animal meat or any commercial plant-based products was determined. Besides that, this research also provides a master curve for correlating the screw speed and OM addition with the extrusion SME. From the master correlation curve, it can be implied that it will be useful for processors and extruder manufacturers to understand the SME reaction at different screw speeds when manufacturing oyster mushroom-soy protein extrudates containing OM at least in this range (0% - 7.5%).

1.5 Thesis Outline

The organization of this thesis is as follows. Chapter 1 introduce the background of the research and the general idea in the development of plant-based meat analog for the substitution of animal meat. This followed by the problems and issues related to this research, the aims and objectives, and the scope and significance of this research.
Chapter 2 presents a review of literatures on introduction plant protein-based meat analog, raw materials and additives properties, and the extrusion processing method of meat analog. This chapter also reviewed on previous findings on the properties (physical, microstructure, texture characteristics) of the protein-based meat analogs with added ingredients.

Chapter 3 describes the materials and experimental procedures for the processing of oyster mushroom-soy protein extrudate. The mashed OM preparation is reported and the overall process of cooking extrusion is explained from the preparation of feed mixtures to the procedure of extrudate storage. The procedures used for analyzing each sample are described. The statistical tool and analysis methods applied are described at the end of the chapter.

Chapter 4 presented the factorial experiment design was successfully used to determine a range of suitable extrusion process parameters that exhibits continuous extrusion flow and unpuff extrudates with a fibrous structure. The effects of extrusion process parameters on the physical characteristic, microstructure and texture characteristics of the extrudate were analyzed using a statistical analysis technique. Besides, this chapter also presented the master correlation curve between screw speeds and OM addition with the extrusion SME using the superposition technique.

The final chapter of the thesis, Chapter 5 summarizes the research works and presented recommendations for future work. The process flow chart of the research design and methodologies applied is shown in Figure 1.1.

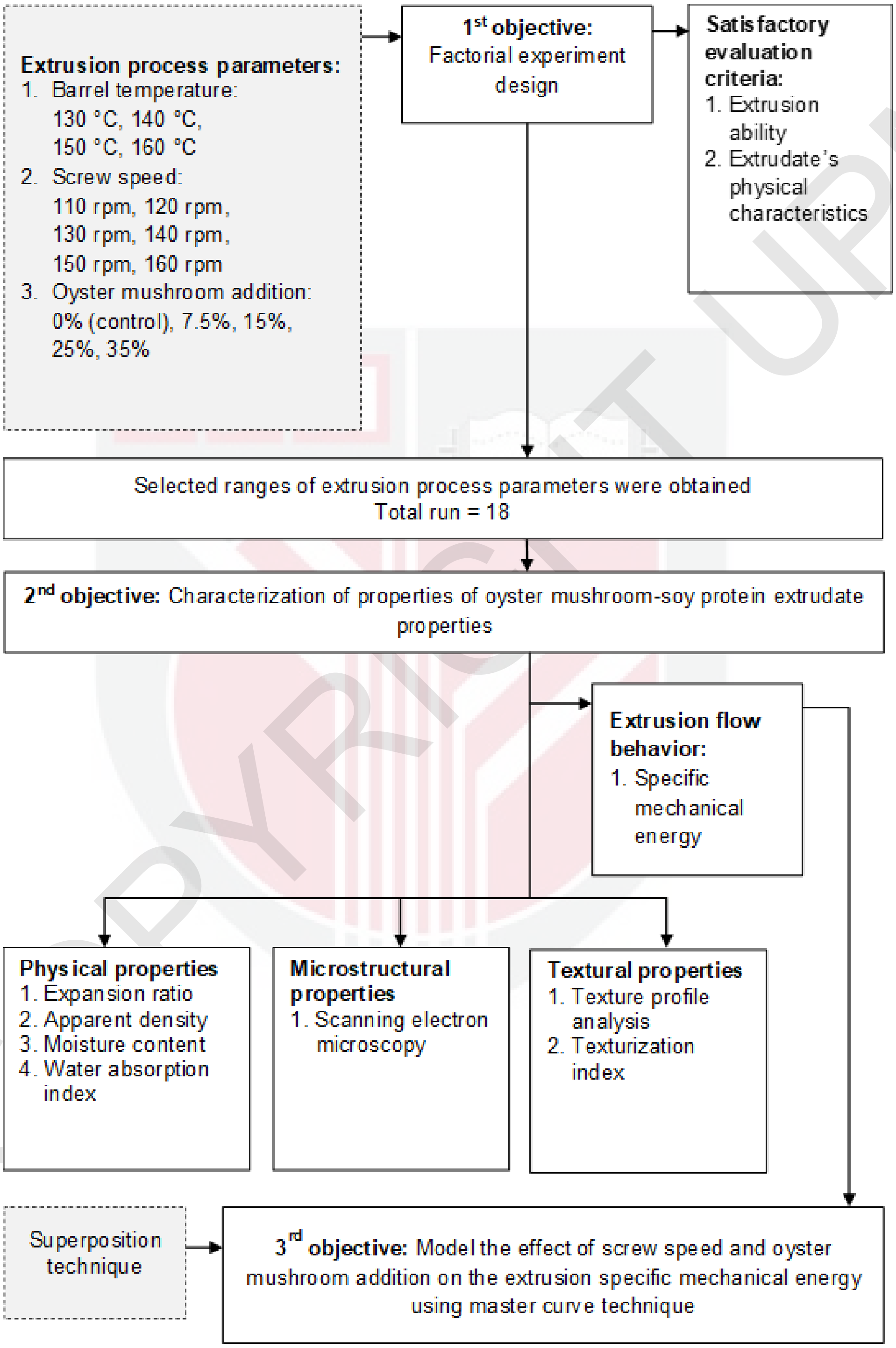

Figure 1.1: Process flow chart of the research design and methodology

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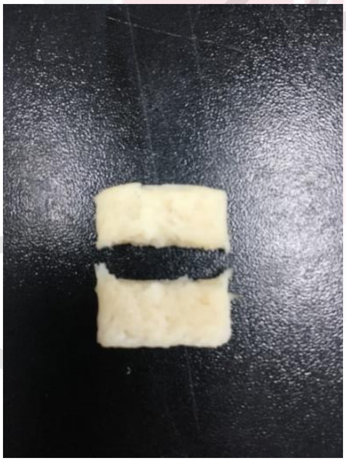
APPENDICES

Appendix A

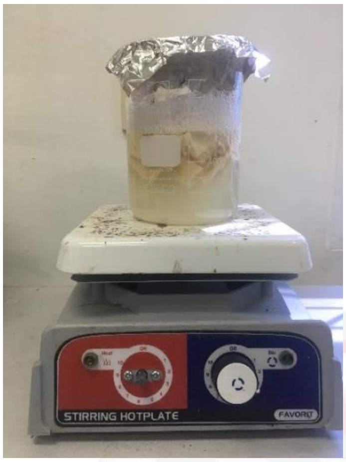
Mechanical textural test procedure

1. Texturization index

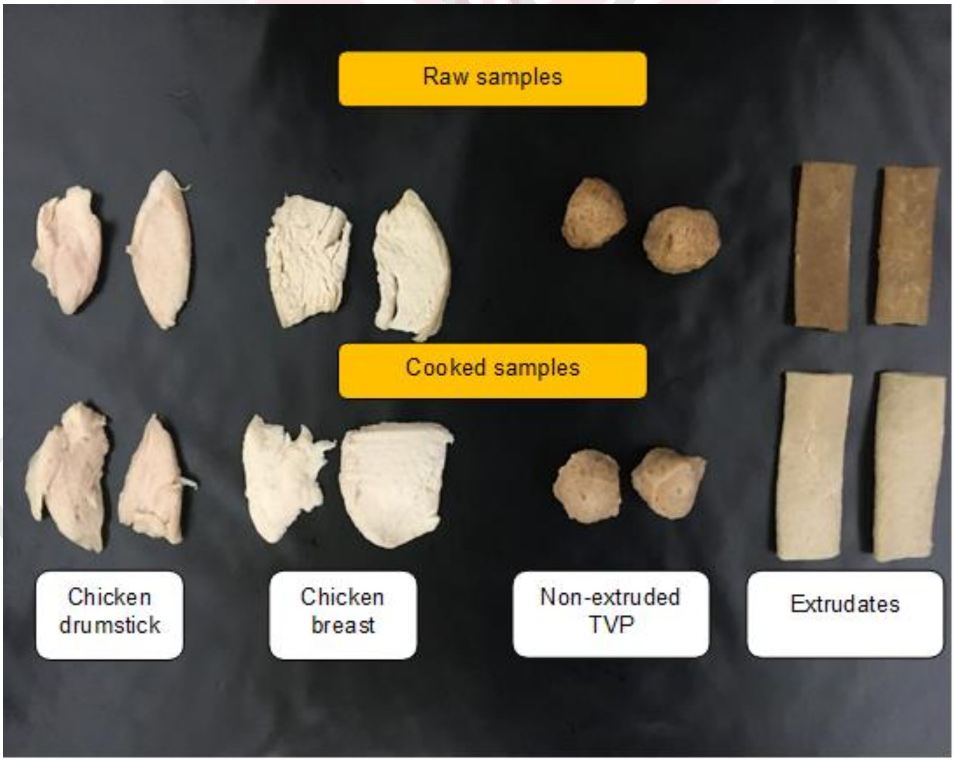


Sample after transverse and longitudinal cutting

2. Texture profile analysis (TPA)

	
Preparation of cooked extrudates	Double-compression test

Reference samples used for comparison of results



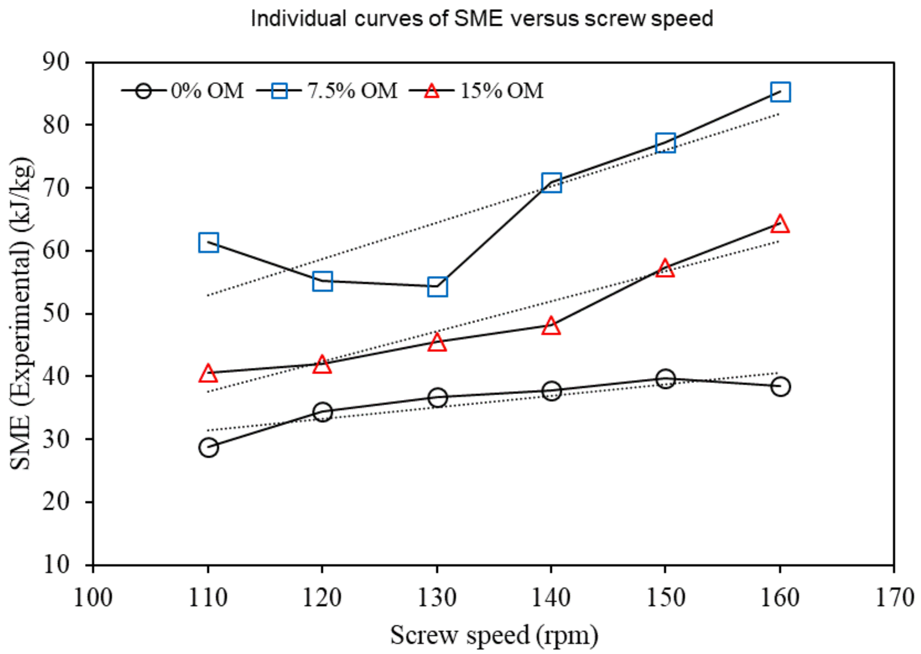
Appendix B

Master curve of SME construction calculation

Oyster mushroom addition (%)	Screw speed (rpm)	SME (kJ/kg)			Standard deviation	Standard error	SME (kJ/kg) (Linear model Y-value)	Sum of square	Total Sum of square	RMSE
		SME 1	SME 2	Average (Experimental)						
0	110	29.18	28.57	28.88	0.426498	0.30158	31.388	6.308773819	50.63861274	1.776059
	120	33.76	35.16	34.46	0.989522	0.6997	33.23	1.513136285	2.347814491	0.869809
	130	36.64	36.83	36.74	0.137438	0.09718	35.072	2.766508034	0.551942442	1.176118
	140	38.64	36.92	37.78	1.214362	0.85868	36.914	0.753587029	3.203168864	0.613835
	150	39.76	39.56	39.66	0.138827	0.09817	38.756	0.815340602	13.44401502	0.638491
	160	37.94	38.95	38.44	0.714466	0.5052	40.598	4.65085031	5.997909403	1.524934
7.5	110	62.15	60.50	61.32	1.165639	0.82423	52.932	70.40562485	36.6859401	5.933196
	120	55.17	55.32	55.24	0.106007	0.07496	58.712	12.02431611	147.2656879	2.45197
	130	53.32	55.34	54.33	1.430379	1.01143	64.492	103.3012592	170.3395804	7.186837
	140	72.02	69.77	70.90	1.586875	1.12209	70.272	0.389009411	12.36231414	0.441027
	150	79.68	74.68	77.18	3.540844	2.50375	76.052	1.274543956	96.06467994	0.798293
	160	86.08	84.53	85.31	1.096736	0.77551	81.832	12.06902771	321.3541211	2.456525
15	110	40.46	40.66	40.56	0.140234	0.09916	37.76	7.821778037	82.94244695	1.977597
	120	41.45	42.45	41.95	0.707189	0.50006	42.558	0.370462523	59.51620895	0.430385
	130	46.31	44.92	45.62	0.982473	0.69471	47.356	3.015474062	16.35822795	1.227899

	140	46.51	49.71	48.11	2.262534	1.59985	52.154	16.3549997	2.415382523	2.859633
	150	57.26	57.41	57.34	0.102772	0.07267	56.952	0.148336161	58.87685885	0.272338
	160	64.95	63.87	64.41	0.761212	0.53826	61.75	7.083703893	217.4888822	1.881981

Plot of SME (Experimental) values versus screw speed were created to find the fitted model



Linear model equation of **Y = ax + c**

	Oyster mushroom addition (%)		
	0	7.5	15
a	0.184	0.578	0.480
c	11	-10.648	-15.018
Mean average	35.992	67.380	49.664
TSSE	16.808	199.464	34.795
TSS	76.183	784.072	437.598
R^2	0.779	0.746	0.920

Find horizontal shifting factor, α

Screw speed (rpm)	SME (kJ/kg) Average (Experimental)	Oyster mushroom addition (%)		
		0	15	7.5
110	28.87627	1.053338	1	0.7474608
120	34.4601	1.228425	1	0.7567875
130	36.73528	1.288932	1	0.7600106
140	37.78209	1.31502	1	0.7614003
150	39.65896	1.359293	1	0.7637586
160	38.44142	1.330927	1	0.7622476
110	61.32281	1.712734	1	0.7825859
120	55.24439	1.635563	1	0.7784751
130	54.32828	1.622759	1	0.7777931
140	70.89571	1.81213	1	0.7878806
150	77.18096	1.866165	1	0.790759
160	85.30605	1.925984	1	0.7939454
110	40.55674	1.379413	1	0.7648304
120	41.94934	1.409368	1	0.766426
130	45.61949	1.481721	1	0.7702802
140	48.10987	1.526026	1	0.7726402
150	57.33714	1.663596	1	0.7799684
160	64.41152	1.747422	1	0.7844337
α -value	Average	1.519934		0.7723157
	STDV	0.23531		0.0125346

X axis-horizontal shift factor, α

Divide X-axis (screw speed) divided by α-value to find the new X-axis values

Oyster mushroom addition (%)	New x-axis values (screw speed, rpm)	SME (kJ/kg) Average (Experimental)
0	72	28.87627
	79	34.4601
	86	36.73528
	92	37.78209
	99	39.65896
	105	38.44142
7.5	142	61.32281
	155	55.24439
	168	54.32828
	181	70.89571
	194	77.18096
	207	85.30605
15	110	40.55674
	120	41.94934
	130	45.61949
	140	48.10987
	150	57.33714
	160	64.41152

Appendix C

Quality grade classification of grey oyster mushroom based on Malaysian Standard (MS2515:2012) (FAMA, 2017)

Grade	Characteristic	Images
Best	• Mature • Fresh • Clean • Free of flaws and physical damage	
Quality accepted by the market	• Mature • Fresh • Clean • Minimum of flaws and physical damage	
Quality not accepted by the market	• Not mature • Not fresh • Dirty • Bad physical damage and shape • Damage caused by pests, disease, and mechanical damage	

BIODATA OF STUDENT

Mazween Mohamad Mazlan was born on 13th July 1993 in Teluk Intan, Perak. She received her primary education at Sekolah Kebangsaan Convent, Teluk Intan, Perak. Later, she continued her secondary education at Sekolah Menengah Kebangsaan Agama Slim River, Slim River, Perak to complete her Sijil Pelajaran Malaysia (SPM) in 2010. After completing her secondary school years, she continued her studies at Perak Matriculation College (KMPk) to complete her foundation level for one year before joining Universiti Putra Malaysia (UPM). Throughout her studies at UPM, she has been actively involved in many faculties and residential college activities. She was also appointed for two years as a member of the Student High Council of Eleventh College, UPM. She excelled not only in co-curricular activities and leadership but also in her academic history. She was awarded the Best Presenter (*Bronze*) of the Open Day Final Year Project and graduated with a Bachelor's degree in Process and Food Engineering in 2016. After graduation, she pursues her Master of Science degree at the Department of Process and Food Engineering, UPM. During her master studies at the Department of Process and Food Engineering, she worked as a demonstrator for undergraduate practical courses, supported final year students with final year projects, and worked as a research assistant. She was also employed as a research assistant at the Universiti Putra Malaysia's Institute of Tropical Forestry and Forest Products. She worked on projects related to the development of active food packaging. She has also been actively involved in many conferences and seminars related to her research project. She won the Gold Medal Award at the UPM Virtual-Material Technology Challenges Competition held in September 2020.

PUBLICATIONS

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Submitted

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